Bioforsk Rapport
Bioforsk Report
Vol. 8 Nr. 73 2013

Inventories as basis for life cycle assessments of milk and meat produced at Norwegian dairy farms

Design and data for three modelled farms with medium production intensity

Johansen[1], A., Daugstad[2], K., Bakken[1], A.K. and Fystro[2], G.
[1]Bioforsk Midt-Norge Kvithamar, [2]Bioforsk Øst Løken

www.bioforsk.no

Hovedkontor/Head office
Frederik A. Dahls vei 20
N-1432 Ås
Tel.: (+47) 40 60 41 00
post@bioforsk.no

Bioforsk Midt Norge
Bioforsk Grovfôr og Kulturlandskap
Bioforsk Midt-Norge Kvithamar
7512 Stjørdal
Tel.: (+47) 40 60 41 00
kvithamar@bioforsk.no

Tittel/Title:

Inventories as basis for life cycle assessments of milk and meat produced at Norwegian dairy farms. Design and data for three modelled farms with medium production intensity.

Forfatter(e)/Author(s):

Astrid Johansen, Kristin Daugstad, Anne Kjersti Bakken, Gustav Fystro

Dato/Date:	*Tilgjengelighet/Availability:*	*Prosjekt nr./Project No.:*	*Saksnr./Archive No.:*
1.7.2013	Open	1210172	2008/1165
Rapport nr./Report No.:	*ISBN-nr./ISBN-no:*	*Antall sider/Number of pages:*	*Antall vedlegg/Number of appendices:*
73 (8), 2013	978-82-17-01094-4	46	1

Oppdragsgiver/Employer:	*Kontaktperson/Contact person:*
Norges Forskninsråd	Astrid Johansen

Stikkord/Keywords:	*Fagområde/Field of work:*
Gårdsnivå; grovfôrproduksjon, inventardata; LCA; mjølkeproduksjon, storfekjøttproduksjon	Grovfôr og kulturlandskap Korn, olje- og proteinvekster
Cattle farming; farm level; forage; inventory data; LCA; meat; milk	Grassland and landscapes Cereal grains and oil- and protein crops

Sammendrag:

I denne rapporten presenteres prosesser og data som grunnlag for en livsløpsanalyse (LCA) av kombinert mjølk- og kjøttproduksjon på tre modellerte norske mjølkeproduksjonsbruk. De tre gårdsbruka representerer hver for seg typiske mjølkeproduksjonsbruk med gjennomsnittlig avdråttsniva og grovfôrproduksjon i sine respektive regioner; Rogaland (Jæren), Nord-Trøndelag (Verdal) og Oppland (Gausdal). Disse områdene ble valgt fordi de representerer tyngdepunkta i norsk mjølkeproduksjon. Datagrunnlaget ble henta fra tilgjengelig statistikk, nyere forskning, samt personlig kommunikasjon med lokalt rådgivingsapparat og gårdbrukere. Rapporten omfatter beskrivelser av bygninger, maskiner og redskaper, samt beregningsmåter og data for forbruk av diesel og olje, gjødsel, kalk, såfrø, sprøytemiddel, gjerdemateriell, plast, ensileringsmiddel, vaskemiddel, medisiner, sagflis, kumadrasser og fôr. Estimerte transportavstander for viktige innsatsmidler (gjødsel, kalk, kraftfôr, sagflis og helsetjenester) er også inkludert. Alle data er på årsbasis og gårdsnivå. Resultatene av den aktuelle LCA-analysen er publisert av Roer et al (2013).

Summary:

The present report outlines the processes and lists the data invented in a Life Cycle Assessment (LCA) of milk and meat produced at three modeled Norwegian dairy farms. The modeled farms represents typical dairy farms of average size and production intensity located in the three most important milk and beef production counties of Norway, i.e. Rogaland, Nord-Trøndelag and Oppland. Information on management and yields was collected from available statistics, results from recent research as well as informal interviews of farmers and supervisors in farmers extension services. Descriptions and data on buildings, machinery and equipment, consumption of diesel and oil, fertilizer, lime, seeds, pesticides, fences, polyethylene and additives for silage production, detergents, medicines, sawdust, cow matrasses, forages, concentrates and mineral supplement are given. Transport distances of major inputs (i.e. fertilizers, lime, feed concentrates, sawdust, and health care service) to the farm are also included. All data presented are on an annual basis at farm

level. The results of the actual LCA are published by Roer et al. (2013).

Land/Country:	Norway
Fylke/County:	Nord-Trøndelag/Oppland
Kommune/Municipality:	Stjørdal/Øystre Slidre/Østre Toten
Sted/Lokalitet:	Bioforsk Midt-Norge/Bioforsk Øst Løken/Bioforsk Øst Apelsvoll

Godkjent / Approved

Ingvar Hage

Navn/name

Prosjektleder / Project leader

Audun Korsæth

Navn/name

1. Foreword

The present report outlines the processes and lists the data invented in a Life Cycle Assessment (LCA) of milk and meat produced at three modeled Norwegian dairy farms (Roer et al. 2013). The farms are not real in the sense that data are collected from existing, single farms, but are supposed to be representatives of traditional medium sized Norwegian dairy farms with an average milk, meat and forage production, with no other animal production except from the dairy herd and its offspring.

The inventory was part of the project ‘Environmental impact and resource use efficiency of selected food production chains in Norway – a life cycle assessment (LCA) approach’, which focused on environmental impacts and resource use efficiencies in important food production chains in Norwegian agriculture. The project was funded by the Norwegian Research Council (program ‘Bionær’).

2. Table of contents

3. Introduction

The combined milk and beef production is a cornerstone in Norwegian agriculture, and is performed all over the country, however canalized to areas less favorable for grain production. In comparison with farms in most other countries in northern Europe, Norwegian dairy farms are still characterized by small production units, even though the average herd size is rapidly increasing. The modeled farms in the present inventory aim to be representatives of those with average sized herds with the coherent traditional farming management, buildings and machinery.

Each of the farms in the present inventory is located in one of the three most important counties for milk production; Rogaland (15 % of total volume), Nord-Trøndelag (12 %) and Oppland (11 %). Climate and general conditions for plant production differs significantly between these geographical areas. However, within each of the selected counties as well as for other regions, there are great variations. This is also the case for animal production. Consequently, it must be noticed that even though the modeled farms are 'typical' in the sense that they are based on valid statistics for the production in the different regions, they may potentially describe dairy farms in other regions as well.

The on-farm processes are divided into two sections; animal production and forage production. The former represents the animal stock and processes in the animal management leading to the delivery of milk and carcasses (from finished bulls and cows), surplus livestock heifers, heifers becoming new dairy cows, and finally; manure from all the animal groups (Figure 4.1). The forage production section is initiated with fallowing and ploughing of old leys and ending with the delivery of pasture or conserved forage at the barn (Figure 4.2). The environmental burdens for manure production are retained within the system, since all manure is recycled within the farm. Animal management includes housing, feeding and milking processes, as well as health and fertility care. Field emissions in plant production and enteric emissions from the animals are important factors not shown in the flow-diagrams.

Descriptions and data on buildings, machinery and equipment, consumption of diesel and oil, fertilizer, lime, seeds, pesticides, fences, polyethylene and additives for silage production, detergents, medicines, sawdust, cow matrasses, forages, concentrates and mineral supplement are given. Transport distances of major inputs (i.e. fertilizers, lime, feed concentrates, sawdust, and health care service) to the farm are also included. Transport of small consumable materials such as polyethylene netting and film, additives, detergents, and mineral supplements are not considered.All data are on annual basis and on farm level.

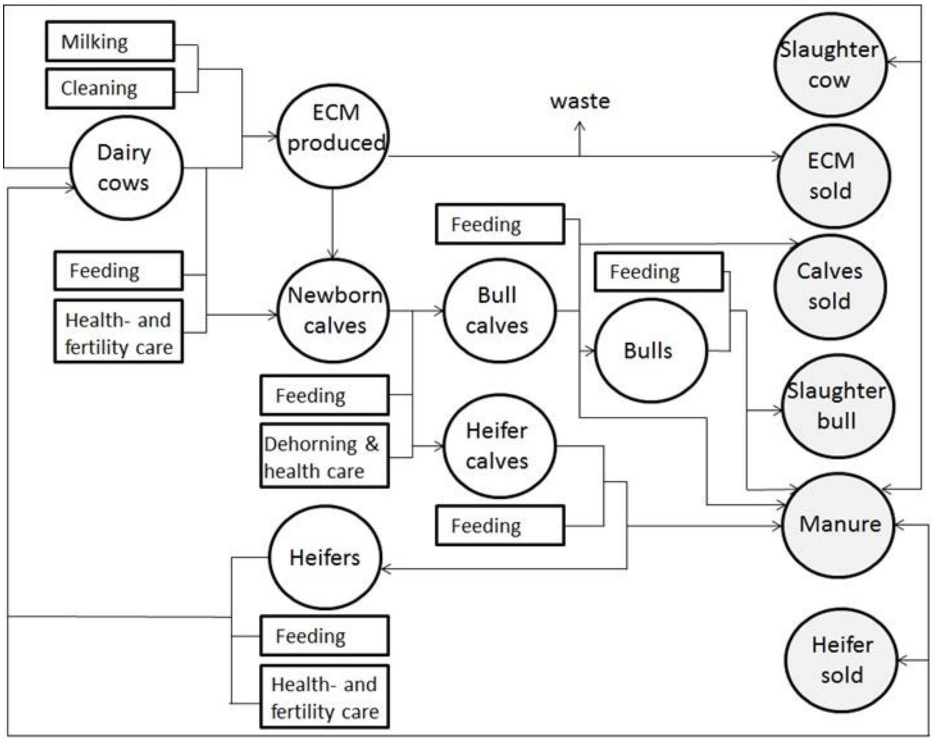


Figure 4.2.1. Flow chart describing processes and intermediary products leading to the products sold from the farm.

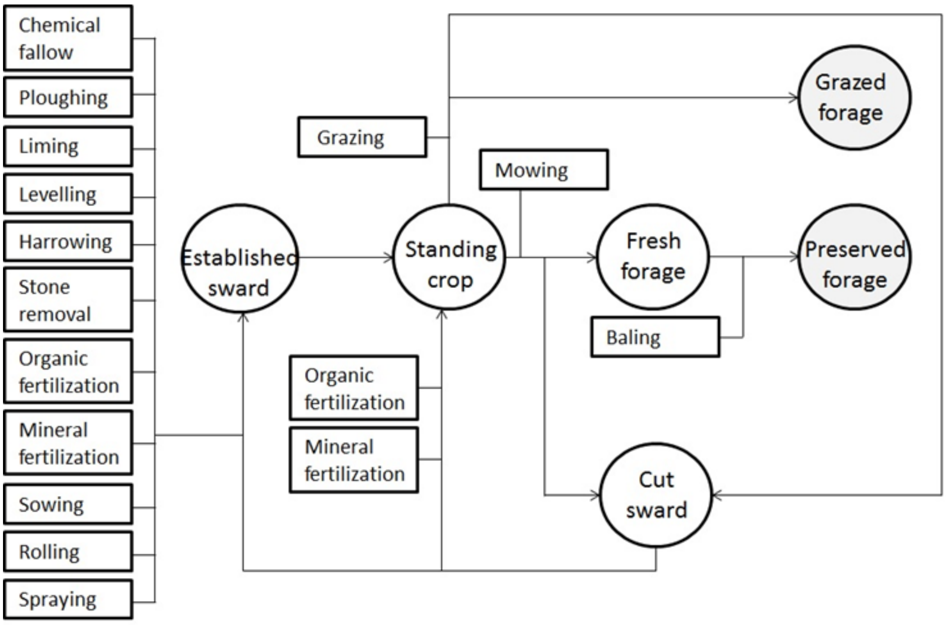


Figure 4.2.2. Flow chart describing processes (rectangles) and intermediary and end products (circles) accounted for in forage production.

4. Sources and rationale for data selection

4.1 Localisation, herd and farm size

Rogaland (SW), Nord-Trøndelag (C) and Oppland (CSE) being the three most important counties for milk production were selected as basis for the acquisition data and modeling work. Part of the grant database of Norwegian Agricultural Authority (2010) that covers the three counties in question was used to establish farm and herd sizes and the partitioning of agricultural land between arable leys for silage and pastures, annual fodder crops and permanent pastures. The data selection was given the restrictions that forage production should be the only plant production, that the quantities of purchased or sold forage should be negligible, that the dairy herd and their offspring should comprise the only animal stock and that most of the offspring should be kept on the farm for recruitment (heifers) or meat production (bulls), that the farm units should be owned by single farmers and, finally, there should be no export or import of manure.

In Rogaland, nearly 50 % of the total milk is produced in the municipalities of Time, Klepp and Hå. Only data from these municipalities formed the basis for the modeling of the SW farm. Mixed animal production (cattle mixed with poultry and/or pig and sheep) is common in this region. Consequently, after having excluded farms with sheep, pig, poultry, suckler cows and/or horse production, farms with cereal production and/or significant amounts of forage sold out of the farm, as well as farms run as co-operatives, only 20 % of the farms (119) were left.

In Nord-Trøndelag 40% of the dairy farms are located in the municipalities of Steinkjer, Inderøy, Levanger and Verdal, all located on the eastern side of the Trondheimsfjord. Data from all the mentioned municipalities were initially considered. After having excluded farms with cereal production, sheep, pig, poultry, suckler cows and/or horse production, and farms run as co-operatives and/or where data on land use were missing, 119 farms (26 % of the total population) were left.

Dairy farming is relatively evenly distributed between different municipalities in the county of Oppland. However, there are huge variations in farming conditions from the fertile soils west of the lake Mjøsa to the valleys and mountainous areas in north and further west. In 2010, Gausdal was the single most important municipality in respect of dairy farming with 119 farming units (Norwegian Agricultural Authority, 2010). By including also the other municipalities forming the mid- and southern part of the Gudbrandsdalen region (Nord-Fron, Sør-Fron, Ringebu, Øyer, Gausdal and Lillehammer), approximately 30 % of the dairy farms in Oppland were covered. After having excluded farms with mixed production and/or co-operatives, 147 farms (36 % of the total poptulation) remained.

Table 5.1.1 Average, minimum and maximum farm and herd size of selected farms[1] in the grant database of Norwegian Agricultural Authority (2010).

	SW	C	CSE
No of farms (after selection)	119	119	147
Dairy cows, (min-max), no	24 (11-53)	20 (11-48)	16 (11-49)
Other cattle, no	47 (15-86)	35 (12-86)	30 (8-133)
Fully cultivated leys and pastures, ha	16.6 (6.9-42.9)	18.5 (5.6-61.9)	17.1 (4.1-47.6)
Surface cultivated land ha	1.0 (0.2-3.1)	1.6 (0.1-10.2)	2.5 (0.1-13.1)
Permanent pastures, ha	4.7 (0.1-23.1)	3.6 (0.1-16.2)	6.0 (0.6-26.5)
Annual forage crops, ha	2.6 (0.3-3.8)	3.5 (0.5-16.0)	2.8 (0.3-10.0)
Total cultivated area, ha	21.0 (9.3-43.3)	22.3 (7.5-61.9)	25.2 (9.0-58.1)

1 General: The data represent dairy farms run by single farmers with milk and forage production only and with dairy herds of 10 cows or more. SW: Data from the municipalities of Hå, Klepp and Time were selected, C: Data from the municipalities of Steinkjer, Inderøy, Levanger and Verdal were selected, CSE: Data from Gausdal, Lillehammer, Nord-Fron, Sør-Fron, Ringebu and Øyer were selected.

The statistics revealed a wide variability within the different regions in both farm size (herd and land) and the distribution of different types of land (cultivated, surface cultivated, permanent pastures and other forages). The average herd size in the selected areas was largest in SW and smallest in CSE (Table 5.1.1) whereas the regions were ranged the opposite way in respect of average agricultural area occupied per farm. Moreover, 50 % of the selected farms in Oppland were granted for having part of their herd grazing in the outfields during the summer season. The corresponding figures for SW and C were 10 % and 13 %, respectively (not shown in Table 5.1.1).

4.2 Animal production

Figures from the National dairy herd recording system, administered by the Norwegian dairy cooperative TINE SA, covering more than 90% of the Norwegian dairy farms, were used to establish figures for milk production and diet composition of the dairy herd, culling ratio, fertility, incident rates of common diseases and meat production. Figures for the period 2008-2010 were used, and for most purposes those reported by TINE Rådgiving (2008 abc, 2009 abc, 2010 abc), based on the assumption that animal production and feeding intensity are not influenced by ownership or herd size.

In the later LCA analysis, data on purchased feeds were based on figures and information received from Felleskjøpet Agri (Roer *et al.*, 2013), being the major subdivision of Felleskjøpet, the market leader on purchased feeds in Norway (65-80%).

We selected some of the articles which were suspected to be of major importance for the environment due to volume and/or contents. These were detergents used for cleaning and disinfection of the milking pipeline and udder-towels, cooling agent for the cooler vat, saw-dust for the bedding in the pens, and the most frequently used medicines. The consumptions of detergents ('Syre' and 'Combi') and disinfection agents (chloride tablets) were based on recommendations given by the producers, the consumption of cooler agent was roughly estimated by a local farmer in an informal interview. The consumption of saw-dust was roughly estimated by Arnt Johan Rygh (TINE Rådgiving, personal com.).

Data on drugs and other inputs related to health and fertility services were based on personal communication with veterinarians. Information about active agents, strengths etc were given by the producers.

4.3 Forage production

4.3.1 Yields

Yields may vary considerably, depending on climate and weather conditions (and consequently years), soils, and management practices, the latter including botanical composition, fertilizing and number of cuts. Data precisely describing forage yields obtained at farms and subsequent losses of dry matter (DM) from standing crop to feed-out of preserved forages are scarce or non-existent. National forage yields reported by Statistics Norway (SSB, www.ssb.no) are related to hay yields, ranging from 5580 to 6590 kg hay ha^{-1} in the period 2000-2009 with Rogaland generally being in the upper part of this range and mountainous areas and/or northern attitudes in the lower part. In TINE Effektivitetsanalyse (completedata from 2010, Kai Espeseth, pers.com.) average net yields expressed as milk feed units (FEm) are estimated to be 6500 FEm ha^{-1} at farms in the selected municipalities in SW, 4600 FEm ha^{-1} in C and 3900 FEm ha^{-1} in CSE.

However, neither of these statistics are based on measurements in field. Statistics Norway is based on rough estimates. The yield data in TINE Effektivitetsanalyse are basically calculated by difference from net energy requirements of the animal stock and consumption of purchased feeds (Walland & Hansen 2003). Yields obtained in plot experiments are often considerably higher than indicated by these data. Bakken et al. (2009) have reported yields of 16 000 kg DM (14 000 FEm) ha^{-1} and 12 000 kg DM in a two cut system in experiments in C and in CSE, respectively. In three and four cut systems in SW, they obtained yields of 13 000 and 12 000 kg DM, respectively. However, it is well known that responses under experimental conditions significantly exceed the responses achieved under farm conditions. Thus, in previous reports, farm DM yields have been set to 60% of the experimental yields (Flaten *et al.*, 2010, with reference to Davidson *et al.*, 1967).

According to 'Gjødslingshåndbok' (http://www.bioforsk.no/ikbViewer/page/prosjekt/tema?p_dimension_id=19190&p_menu_id=19211&p_sub_id=19191&p_dim2=19603), expected net energy yields in moderately fertilized two cut systems in C and CSE are approximately 5000 FEm ha^{-1}. The corresponding value for a three cut system in SW is 6000 FEm ha^{-1}. According to these guidelines, approximately 50-75 % of the expected yields in established leys may be obtained in the year of establishment, whereas yields from moderately or extensively fertilized surface cultivated pastures are 1500-2500 FEm ha^{-1}.

4.3.2 Fertilization, liming and plant protection

The fertilization and liming were based on recommendations given by Bioforsk (2010) and discussion with the local Agricultural Advisory Agencies.

Only 6% of the total area with leys and pastures in Norway are treated with pesticides (http://www.ssb.no/jord-skog-jakt-og-fiskeri/statistikker/jordmil). The pesticides used are by all means herbicides related to fallowing of old, and establishment of new leys. The decisions on type and amount of pesticides selected were based on recommendations given by Norwegian Agricultural Advisory Agencies (pers.comm.).

4.3.3 Harvesting, preservation and forage quality

Ten years ago, between 40 and 50 % of the silage was preserved in round bales in Norway (Moe 2005). Since then, the proportion has increased and is presently assumed to be above 60% in all regions.

The DM-content of a total of 3000 samples of big bale silage from all over the country analysed during the period 2008-2010 was in the range 20 -40% (TINE 2008, 2009, 2010). Approximately 56 % of the samples represented big bale silage conserved with different types of additives, out of which Ensil 1 was the most frequent (37%). Apparently, there were no differences in DM contents between big bale silage conserved with and without perseverative. Moreover, differences between big bale silage and traditional silage (bunker, tower) were also negligible. Figures for different counties were not presented in the reports studied. However, especially in the humid climate at the Atlantic coast in SW and C, it is a challenge to produce wilted silages. The target DM content of 28-30 % (Moe 2005) is not always reached.
According to sales data, less preservative are used in CSE compared to SW and C (Felleskjøpet Agri, pers.comm.).

The bales are typically wrapped with 4-8 layers of polyethylene film. The weight of each bale varies according to the baler. The mean weight for bales from new combi-balers tested by Degerdal *et al*. (2011) was within the interval 800-900 kg. For the modeled farms with machinery of older origin, we chose a lower mean weight (700 kg, Berg 1997) which caused a higher consumption of both polyethylene film and diesel than reported in comparable inventories (Flysjø *et al*., 2008).

Approximately 2000 feed samples of 1st cut big bale silage and half the amount with 2nd cut big bale silage from Norwegian dairy farms are annually analyzed for chemical composition and nutritive value, reported in the National dairy herd recording system. The decision on forage quality at the model farms was based on the average statistics as presented by Tine Rådgiving (2008abc, 2009abc, 2010 abc). According to these statistics net energy contents of silage may typically vary from 0.85 to 0.90 FEm kg DM^{-1} in the selected municipalities of SW, from 0.83 to 0.88 in C and from 0.83 to 0.85 in CSE. We only considered net energy contents. The crude protein (CP) content of silage is typically 15 % for all the selected areas.

The statistics from TINE does not include analyses of fresh herbage from pastures. For this purpose figures from 'Fôrmiddeltabellen' (http://www.umb.no/iha/artikkel/fortabellen) and experimental data for Italian ryegrass (Johansen & Lunnan, 2005) were considered.

4.4 Buildings, machinery and equipment

4.4.1 Outdoor machinery and equipment

Farm infrastructure is described briefly. We have reported only what is considered necessary for the production of forage on dairy farms of the actual size and described production system. It should be mentioned here that machinery being older than the expected lifetime, will contribute to the environmental impact through the use of diesel and lubrication only.

Service time for the different items was set according to Ecoinvent (Nemecek *et al.*, 2004), where the total range for listed machinery and equipment was 10-20 years. There were no figures for sprayer, leveller, baler, bale gripper and bale lifter in this report. The service time for leveller was set as for roller. For the other items, service time was subjectively chosen within the range 10-20 years.

4.4.2 Buildings and indoor equipment

Since the new animal welfare legislations in 2004, only buildings with loose housing systems have been planned and build in Norway (http://www.regjeringen.no/nb/dep/lmd/dok/lover_regler/forskrifter/2004/forskrift-om-hold-av-storfe-f-1072.html?id=92442). However, buildings from the 1980'swith a traditional stanchion barn, slurry storage in the basement and dung removal by force of gravity and limited indoor mechanization are still highly representative for farms of the actual size and production. Consequently, a construction plan by Gjerde (1990) was used in the inventory (Appendix). A Swiss building of approximately the same size but without a slurry store included, has been given a service time of 50 years (Nemecek *et al.*, 2004) whereas a slurry storage (concrete tank) is given a service time of 40 years. Based on these figures, a service time of 40 years was set for the barns in the present inventory.

Additionally, sheds for outdoor machinery are common.

4.5 Energy consumption

4.5.1 Diesel

The diesel consumption for all field work processes were estimated through a stepwise procedure. In the first step we used a Danish model 'Drift' (Nielsen & Sørensen, 2010) to calculate the number of man hours needed to perform the various operations with the available equipment under the given conditions. To do these calculations, assumptions regarding the speed of different operations had to be made. The local extension service (Atle Haugnes, Norsk Landbruksrådgivning Sør-Trøndelag) was consulted on this matter. Secondly, and after discussions with the extension service, we decided if the workload of the operations was light, medium or heavy and calculated the diesel needed per hour by using conversion factors 0.12, 0.19 and 0.25 L diesel per kW motor effect, respectively (Romerike landbruksrådgivning). For some of the processes, we chose workloads in between these factors. The diesel requirement per ha or feed unit was finally calculated.

The consumption of lubrication oil was considered proportional to the diesel consumption (Dalgaard *et al.*, 2001) and set at 0.62% of the diesel consumption (Refsgaard *et al.*, cited by Dalgaard *et al.*, 2001).

4.5.2 Electricity

According to the account statistics from NILF (2008, 2009, 2010), the average electricity costs at 20-cow herds in C was 26920 NOK in the period 2008-2010. Corresponding data for dairy farms in CSE was 26000 - 32000 NOK, and for the SW area 20000 – 38000 NOK (NILF 2008, 2009, 2010). These figures represent farms with 24 (CSE) and 36 cows (SW).The account statistics include costs related to the consumption as well as the net charge. According to historical data from Nord-Trøndelag Elektrisitetsverk, NTE (www.nte.no), net charge costs has been relatively stable (approximately 0.44 NOK kWh^{-1}) whereas costs related to consumption has increased from 0.40 to 0.45 NOK kWh^{-1} in the actual period. Based on the later figures, we assumed that consumption account for 50 % of the total costs. Consequently, for a dairy farm with a herd of 20 cows, the annual electricity expenditure in Central Norway was approximately 26000 kWh. As a simplification we used the same electricity expenditure for all three modelled farms, based on the expectation that a milder climate in SW compared to CSE and C compensated for a larger building and more cows to be milked.

5. Inventory of the farms

5.1 Main characteristics

Three farms were modelled. The farms were located in Klepp, Verdal and Gausdal, municipalities with comprehensive dairy farming in the three most important dairy farming counties of Norway. In the following, the farms will be referred to as 'southwest' (SW), 'central' (C) and 'central southeast' (CSE), respectively.

The farms were assumed managed according to a medium intensity in plant and animal production, and with land, machinery, equipment and buildings typical for the actual farm size and localization). The herds comprised 20 (C, CSE) or 24 (SW) dairy cows of the Norwegian Red Cattle breed and their offspring. The annual delivery of milk to the dairy plant varied from 132 000 kg to 164 000 kg and the annual delivery of carcasses to the slaughter house from approximately 5400 to 7000 kg (Table 6.1.1). The milk delivery corresponded to 92-93 % of the total recorded milk yield. The 7-8 % not delivered was partly waste, partly offerings to young calves and partly household use. With the exception of young calves, all animals were offered on-farm produced grass silage and mixed concentrates during the indoor feeding season. In the summer, heifers and cows were assumed to graze on the farm area with additional feeding with silage and/or concentrates and mineral supplements. In CSE heifers older than 12 months were assumed to graze in the outfields for two months.

The SW farm was located on sandy loam 10 km from the North Sea, C on clay loam 10 km from the Trondheimsfjord, and CSE on silty sand nearby a major waterway running 235 km south to the Oslofjord. The soils contained 3-6 % organic material in the plough layer (Table 6.1.2), and the erosion risks were regarded as low (SW), medium-high (C) and medium (CSE), according to official classifications (The Norwegian Forest and Landscape Institute, 2011). The length of the growing season, defined as the number of days with mean temperature of 5 °C or more, differed from 210 days in SW to 165 days in CSE, whereas the mean temperature during the growing season was 11-12 °C at all locations.

Table 5.1.1. *Main characteristics of the herds and forage production at three modelled dairy farms in southwest (SW), central (C) and central southeast (CSE) Norway. All figures are per annum.*

	SW	C	CSE
Animal production			
Cows (units)	24	20	20
Offspring, bulls and heifers (units)	48	40	40
ECM yield (kg cow^{-1})	7 350	7 250	7 100
ECM delivered to dairy plant (kg)	164 000	133 000	132 000
Cow carcasses delivered to slaughter plant (units)	12	9	9
Cow carcass weight (kg carcass^{-1})	270	270	270
Cows, concentrate of total energy intake (%)	35	39	39
Cows, pasture of total energy intake (%)	17	13	10
Heifers, age at calving (months)	25	25	25
Heifers, 24 months, livestock sales (units)	0	1	1
Heifers, concentrates of total energy intake (%)	21	19	19
Heifers, pasture of total energy intake (%)	42	33	33
Bulls, age at slaughter (months)	20	18	17
Bulls, carcasses delivered to slaughter plant (units)	12	10	10
Bulls, carcass weight (kg carcass^{-1})	313	300	300
Bulls, concentrates of total energy intake (%)	34	40	48
Stored manure (Tonnes, 6.5% DM)	942	806	791
Energy, direct usage			
Diesel, forage production (Litre)	4800	3900	3400
Electricity, housing and milking (kWh)	26 000	26 000	26 000
Agricultural land			
Arable land (ha)	21.5	22.5	21.5
Permanent pastures (ha)	3.0	2.0	3.5
Outfield pastures			Yes
Leys, year of establishment			
Cuts (units)	2	1	1
DM yield (kg ha^{-1})	4300	3500	3300
Leys, 1st-4th year			
Cuts (units)	3-4	2	2
DM yield (kg ha^{-1})	8400	7000	6600
Italian ryegrass, DM yield (kg ha^{-1})	8500	-	6000
Permanent pastures, DM yield (kg ha^{-1})	5000	2500	2500
DM content of wilted grass and silage (%)	26.0	26.0	28.0
Net energy content of forages[1] (FEm kg DM^{-1})	0.87	0.85	0.85

Abbreviations; DM: Dry matter, FEm: Milk feed units (1 FEm=6.9 MJ NE_L), ECM: Energy corrected milk. [1] Exception: Net energy content of Italian ryegrass pastures in SW and CSE was set to 0.9 FEm kg DM^{-1})

Table 5.1.2. Climatic conditions, soil characteristics and altitudes *at three modelled dairy farms in southwest (SW), central (C) and central southeast (CSE) Norway.*

	SW	*C*	*CSE*
Annual			
Temperature °C	7.2	4.7	2.5
Precipitation mm	1260	900	720
Growing season			
Days with temp > 5 °C	210	180	165
Mean temperature °C	11.3	11.6	11.75
Soil	Sandy loam	Clay loam	Silty sand
Soil organic matter content, %	6	3-6	3-6
Altitude, meter above sea level	35	70	350

5.2 Animal production

We made the assumption that the animals were sufficiently supported with nutrients (fat, protein, vitamins and minerals) from the calculated diets based on net energy requirements (Sundstøl & Ekern, 1992). The number of individuals in different animal groups and their total intake of different feeds and supplements are given in Table 5.2.1. In addition, heifers in CSE were supplied with a total 3600 FEm from outfield pastures in CSE.

Table 5.2.1 *Number of individuals in different animal groups and their total intake of mineral supplements (kg), mixed concentrates, fresh forage from permanent pastures and leys, and silage (FEm[1]) as calculated for three modelled dairy farms located in central, central southeast and southwest Norway*

Animal group	**Number of individuals**	**Mineral supplement kg**	**Concentrate FEm**	**Pasture permanent FEm**	**Pasture, arable land FEm**	**Silage FEm**
Central						
Dairy cows	20	180	40880	0	13123	50978
Heifer calves	10	60	3681	2125	2315	3384
Bull calves	10	0	6839	0	0	8755
Heifers	10	180	2954	2125	5015	13641
Bulls	10	0	5238	0	0	9582
Central southeast						
Dairy cows	20	180	40600	0	10289	51997
Heifer calves	10	60	3681	2898	542	3381
Bull calves	10	0	9506	0	0	9407
Heifers	10	75	2954	3540	0	13641
Bulls	10	0	5820	0	0	6930
Southwest						

Dairy cows	24	216	44100	0	21505	60893
Heifer calves	12	90	4164	6693	0	2949
Bull calves	12	0	6400	0	0	11208
Heifers	12	270	3015	6357	4479	14028
Bulls	12	0	7200	0	0	16992

(1) FEm: Milk feed units, Norwegian net energy value for ruminants (1 FEm=6.9 MJ NE_L)

5.2.1 Dairy cows

The inventory was based on the assumptions that the dairy cows, each with a liveweight (LW) of 550 kg, produced an amount of of 7350 kg (SW), 7250 kg (C) and 7100 kg (CSE) energy corrected milk (ECM) annually, and that each cow raised one calf each. One kg of ECM contained 4.2 % fat 3.5 % protein and 4.7 % lactose, the ratio of bull and heifer calves is 50:50, and the replacement rate was 50 % (SW) or 45 % (C, CSE). Consequently, 12 (SW) and nine (C, CSE) cows were slaughtered every year. The carcass weight was assumed to be 50 % of the LW, i.e. 270 kg. The calving frequency was highest in late autumn (September-December).

The cows were fed round bale silage contributing 48 % (SW, C) or 51 % (CSE), pasture 10-17 % and mixed concentrates 35 % (SW) or 39 % (C, CSE) of the total net energy requirement. During the indoor season they were offered round bale silage and concentrates only. In the grazing season (SW: 150 days, C and CSE: 110 days) they were kept on pasture at daytime (12 hours). During the night (12 hours) they were kept indoors, offered concentrates and restricted amounts of silage. Dry cows were offered mineral supplements additionally to silage and/or pasture.

Inseminations and health care were administered by the local veterinarians. Production and storage of semen was not taken into account whereas small amounts of anticeptics (chlorhexidin) used at insemination were included. Antibiotic treatments against mastitis (0.23 incidents cow^{-1}) were the only medical ‘treatments’ included. We assumed that one injection with benzylpenicillinprokain was given at each incident. Additionally, daily intra-mammary injections with an ointment of either benzylpenicillin (50 %) or a mixture of benzylpenicillin and sulphate (50%) were given during a period of 4-5 days. Data on antibiotics, other medications as well as anticeptics used in the herd are given in Table 5.2.2

Table 5.2.2. *Purpose, trademark, amounts, active agents and price (NOK) of medicines and antiseptics included in the inventory of three modelled Norwegian dairy farms*

Purpose	Trademark	Amount	Active agent	Strength
Mastitis	Penovet	600 ml	Benzylpenicillinprokain	300 mg/ml
Mastitis	Mastipen	120 g	Benzylpenicillinprokain	300 mg/g
Mastitis	Streptocillin Forte Vet	72 g	Benzylpenicillinprokain / Dihydrostreptomycinsulfat	500 mg/g
Dehorning	Comforion vet	1600 ml	Ketoprofen	100 mg/ml
Dehorning	Lidokel-Adrenaline vet	1600 ml	Adrenaline	100 ml/dose
Dehorning	Narcoxyl vet	1600 ml	Xylazine	20 mg/ml
Gastro-intestinal nematodes and worms	Systamec Repidose	12 ruminal boluses	Oxfendazol	750 mg/bolus
Insemination, dehorning	Clorhexidin	20 Litre	Chlorhexidin diacetate	5 mg/ml

5.2.2 *Calves*

Still born calves and calves that died shortly after birth were indirectly accounted for when assuming that one calf per cow was raised per year. The new born calves were offered whole milk produced on-farm (350 kg ECM calf^{-1}) during their first two months of living. Other feed consumptions were assumed to be zero during this period. After weaning at eight weeks, the calves were offered concentrates and silage.

Dehorning of 65 % of the calves within two months age, including use of anaesthetics (Ketoprofen, Adrenaline and Zylazine) and antiseptics (Chlorhexidin diacetate), were taken into account (Table 5.2.2).

5.2.3 *Heifers*

Forage intake by heifers was calculated by difference: total net energy requirements minus net energy intake from on-farm produced milk and purchased concentrates according to feeding recommendations given by (TINE 2010a; Felleskjøpet 2010a). All heifers were assumed to have two grazing seasons á 150 (SW) or 120 (C, CSE) days before their first calving and pasture contributes 33 % (C, CSE) - 42 % (SW) of their total forage intake.

The heifers were inseminated for the first time at the age of 13-15 months, and had their first calf at the average age of 25 months. The 25th month was included both in the computations of feed consumption and manure production. One surplus heifer (C, CSE) was sold as livestock shortly before the expected time of calving. However, a complete recruitment period of 25 months was taken into account even for this heifer.

Rumen boluses against intestinal worms were applied to all heifers before their first grazing season. Other medical or fertility treatments were not accounted for.

5.2.4 Bulls

The bulls were supposed kept indoors for their entire life and finished at 626 kg LW (SW) or 600 kg LW (C, CSE) within 18 months (SW, C) or 17 months (CSE). A dressing percentage of 50 % was assumed. The bulls were fed according to feeding standards (Ekern & Sundsøl 1994) and recommendations for concentrate feeding given by TINE (2010b) and Felleskjøpet (2010a) for the corresponding live weight gain (SW, C: 1000 g day^{-1}, CSE: 1100 g day^{-1}). As for the heifers, forage intake was computed by difference (net energy requirement minus net energy supply from purchased concentrates).

It was assumed that the bulls were healthy and in no need of medication or other veterinary treatments.

5.2.3. *Daily excretion of manure (kg head^{-1}), annual N-excretion (kg head^{-1}) and relative amounts (%) stored or dropped at pasture at three modelled dairy farms in southwest, central and central southeast Norway.*

Animal group	**Number of individuals**	**Grazing days**	Kg manure head^{-1} day^{-1}	Kg N head^{-1} yr^{-1}	**Amount stored**	**Amount droppings**
Southwest						
Dairy cows	24	150[1)]	56	102	80 %	20 %
Heifer calves	12	150	15	29	59 %	41 %
Bull calves	12	0	15	24	100	
Heifers	12	150	30	35	59 %	41 %
Bulls	12	0	35	35	100	
Central and Central southeast						
Dairy cows	20	110[1)]	56	102	85 %	15 %
Heifer calves	10	120	15	29	67 %	33 %
Bull calves	10	0	15	24	100 %	
Heifers	10	120	30	35	67 %	33 %
Bulls	10	0	35	35	100 %	

[1)] The dairy cows are spending only half the day at pasture during the grazing period. Consequently, we assume that only half the amount of manure produced during the grazing period is deposited at pasture. The other half is deposited indoors and credited the stored amount.

5.2.5 *Manure production*

The figures for daily excretion of manure (kg and kg N) by bulls and heifers (Table 5.2.3) are according to The Norwegian Emission Inventory (SSB, 2010) whereas corresponding figures for the dairy cows are based on data published by Hoen *et al.* (2007).

It was assumed that the stored manure (total manure minus the droppings during grazing) was mixed with water during storage and before spreading, reaching a DM content of 6.5 %. The total amount of stored manure then became 806, 791 and 942 tons for C, CSE and SW respectively (Table.6.2.1). Lower amounts of manure in CSE compared to C, despite that the number of animals is equal, were due to the fact that bulls in CSE were slaughtered approximately one month earlier than in C.

5.2.6 *Purchased feeds*

We assumed that all mixed concentrates and mineral supplements were produced by Felleskjøpet Agri (Table 5.2.4)

Table 5.2.4. *Land of origin and relative weight contribution of different ingredients in mixed concentrates (C and CSE: FORMEL Favør 80, SW: FORMEL Elite 80) and mineral supplements on the modelled farms*

Ingredients	Land of origin	FORMEL Favør 80	FORMEL Elite 80	Mineral supplement
Urea	Germany	0.002		
Soybean meal	Brasil	0.085	0.080	
Rape meal	Baltikum	0.080	0.080	
Rape beans	Norwegian/import 50/50	0.025	0.020	
Molasses	Pakistan	0.050	0.060	0.06
Lime	Norwegian	0.009	0.008	
Magnesium oxide	Spain	0.003	0.004	
Sodium chloride	Germany	0.007	0.007	0.14
Sodium sulphate	Germany/France	0.001	0.001	
Chemical inorganics	Sweden	0.002	0.002	0.31
Soybean oil	Brasil			0.01
Sodium phosphate	Sweden			0.07
Barley	Norwegian	0.400	0.450	0.071
Oat	Norwegian	0.280	0.220	
Wheat	Norwegian	0.050	0.060	

[1]Crude protein= N x 6.25

5.2.7 *Medicines and other articles of consumption*

In the present inventory a few medicines (Table 5.2.5), cleaning and cooling agents for the milking equipment (Table 6.9.2), cow-matresses (M45S, DeLaval) and saw-dust (Table 6.9.1) were taken into consideration. Other small articles of consumption (i.e. towels, feeding buckles and nipples, paper, rubber parts of the milking pipeline etc.) were not included.

Table 5.2.5. *Purpose, trademark, amounts, active agents and price (NOK) of medicines and antiseptics included in the inventory of three modelled dairy farms located in central, central southeast and southwest Norway*

Purpose	Trademark	Amount	Active agent	Strength	Price NOK
Mastitis	Penovet	600 ml	Benzylpenicillinprokain	300 mg/ml	670
Mastitis	Mastipen	120 g	Benzylpenicillinprokain	300 mg/g	250
Mastitis	Streptocillin Forte Vet	72 g	Benzylpenicillinprokain / Dihydrostreptomycinsulfat	500 mg/g	200
Dehorning	Comforion vet	1600 ml	Ketoprofen	100 mg/ml	100
Dehorning	Lidokel-Adrenaline vet	1600 ml	Adrenaline	100 ml/dose	30
Dehorning	Narcoxyl vet	1600 ml	Xylazine	20 mg/ml	50
Gastro-intestinal nematodes and worms	Systamec Repidose	12 ruminal boluses	Oxfendazol	750 mg/bolus	1370
Insemination, dehorning	Clorhexidin	20 L	Chlorhexidin diacetate	5 mg/ml	1470

The consumption of cleaning and cooling agents was based on recommendations given by the producers as well as information collected from local farmers.

Table 5.2.6. *Amounts (litre and kg) of cleaning and cooling agents included in the inventory of three modelled dairy farms in central, central southeast and southwest Norway.*

	Total amount	Volume weight	Total amount, kg
Cooling liquid	13 L	1.12 kg /l	15.6 kg
Acid detergent	45 L	1.2 kg/l	54.0 kg
Alcaic detergent	45 L	1.2 kg/l	54.0 kg
Chloride	730 tablets	$2.7x10^{-3}$ kg/tablet	1.97 kg

Table 5.2.7. *Amounts of sawdust (kg) and number of cow mattresses included in the inventory of three modelled dairy farms in central, central southeast and southwest Norway*

Process	unit	Central	Central southeast	Southwest
Sawdust	m^3	55	55	70
Mattresses	units	20	20	24

5.3 Forage production

5.3.1 Crop rotation, field management and yields

Leys on arable land were ploughed, limed and re-sown every 5th year with field management practice as illustrated in Figure 4.1. Ploughing was performed in the autumn on four year old leys, after spraying with glyphosate. The next winter/early spring the area was limed and the soil levelled before stone removal and manure application. After immediate harrowing, the area was fertilized with mineral fertilizer, sown and rolled. After germination of grass and clover, herbicides (a mixture of MCPA and tribenuronmethyl) were applied. At SW, the newly established sward was cut twice while the leys in the following four years were cut three or four times. At C and CSE, the newly established swards were cut once and thereafter twice per season for the four subsequent years. The leys in C and CSE were seeded with a mixture of 70 % timothy, 20 % meadow fescue and 10 % red clover. In SW the same seed mixture was used on 60 % of the area. On the rest, a seed mixture of 90 % perennial ryegrass and 10 % white clover was used. Grazing (dairy cows) replaced one or two cuts on some of the area (1-2 ha). Moreover, in SW and CSE, Italian ryegrass grazed by dairy cows, were grown on 2.0 ha every year. Cut and grazed sward constituted the potential for a new cycle of forage production. One fifth was, however, fallowed and re-established as a new sward the following year.

On established leys manure was spread in spring and after the 1st cut. On 1st year ley in CSE however, only mineral fertilizer is applied. The total amount of stored manure (Table 5.2.3) was distributed on fully cultivated land (Table 5.3.1). The manure was spread by use of a manure tanker with splash plate spreader.

Table 5.3.1 *The amounts and types of fertilizers, , lime, seeds and herbicides used in forage production processes at three modelled dairy farms in central (C), central southeast (CSE) and southwest (SW) Norway. (Est.ley=establishment of ley).*

Process	Commodity	Farm	Crop (type)	Area (ha)	Dosage (kg ha^{-1}yr^{-1})
Fertilization	Manure	SW	Est.ley	3.9	65 700
		SW	1st-4th yr ley	15.6	43 800
		SW	It.ryegrass	2.0	65 700
	Manure	C	Est.ley	4.5	53 700
		C	1st-4th yr ley	18.0	35 800
	Manure	CSE	Est.ley	3.9	82 500
		CSE	2nd-4th yr ley	11.7	40 000
		CSE	It.ryegrass	2.0	82 500
	OPTI NS^{TM} (1)	SW	Est.ley	3.9	284
		SW	1st-4th yr ley	15.6	733
		SW	It.ryegrass	2.0	729
		SW	Perm.past	3.0	592
	OPTI NS^{TM} (1)	C	Est.ley	4.5	173
		C	1st-4th yr ley	18	616
	OPTI NS^{TM} (1)	CSE	Est.ley	3.9	132
		CSE	It.ryegrass	2.0	255
		CSE	1st-4th yr ley	15.6	532
	NPK-fertilizer(2)	CSE	Perm.past.	3.5	120
Liming	AgriDol	SW	Est.ley	3.9	4000
		SW	Perm.past	3.0	3400(3)
	Franzefoss AgriGrov VK	C	Est.ley	4.5	4040
	Grovkalk	CSE	Est.ley	3.9	4000
Sowing	Timothy-based seed	SW	Est.ley	1.6	35
	mixture (60 %) or	SW	Est.ley	2.4	25
	perennial ryegrass-	SW	It.ryegrass	2.0	40
	white clover mixture.	SW	Perm.past	3.0	20(4)
	Timothy-based seed	C	Est.ley	4.5	25
	mixture	CSE	Est.ley	3.9	25
		CSE	It.ryegrass	2.0	40
Fallowing	Glyphosate	SW, CSE	Est.ley	3.9	1.44
	Glyphosate	C	Est.ley	4.5	1.44
Spraying	MCPA	CSE	Est.ley	3.9	0.375
	MCPA	C	Est.ley	4.5	0.375
	MCPA	SW	Est.ley	3.9	0.375
		SW	Perm.past	3.0(5)	0.375(5)
	Tribenuronmethyl	SW	Est.ley		0.00375
		SW	Perm.past		0.00375(5)
	Tribenuronmethyl	C	Est.ley		0.00375
	Tribenuronmethyl	CSE	Est.ley		0.00375

(1) N fertilizer with N (27 %)
(2) Compound fertilizer with N (24.6 %), P (2.8 %), K (6.0 %)
(3) Every 5.5th year
(4) Every 3rd year
(5) Every 5th year

Mineral fertilizer was applied to meet the total amount of N, P and K required, according to Bioforsk (2010) for the given site and at medium production intensity. Fertilizer effect from one ton of manure was assumed to amount to 1.5 kg N when harrowed into the soil (year of establishment) and to 1.0 kg when surface spread (1^{st}-4^{th} year leys). Permanent pastures were fertilized with droppings from the grazing animals and small amounts of mineral fertilizer. Pastures at C excepted where no mineral fertilizer is applied. In SW, the permanent pastures were limed every five and a half years, sprayed with herbicide every fifth year, and reseeded by direct drilling every 3^{rd} year.

To establish grass DM yields for the model farms, expert opinions (Norsk Landbruksrådgiving, pers.com.) and Bioforsk (2010) were considered. The final net yields were however adjusted to calculations of animal consumption with the addition of 13-14 % of silage losses.

5.3.2 Harvesting, preservation and forage quality

Forage cut for preservation was wilted to 26 % DM (SW, C) and 28 % DM (CSE). A preservative (Ensil ®1, Felleskjøpet) consisting of 75 % formic acid and 8 % Na, was applied in SW and C (Table 5.3.2) according to recommendations given by the producer. Round bales (700 kg each) were wrapped in a polyethylene net and six layers of high-density polyethylene film (Triowrap AB No 718). The bales were collected and stored at field side. Later they were transported on a trailer (eight bales per load) to the barn.

Table 5.3.2. *Total amounts of polyethylene and additives used for preservation and sealing of big bale silage at three modelled dairy farms in central (C), central southeast (CSE) and southwest (SW) Norway*

Commodity	Dose	Southwest	Central	Central southeast
Preservative	4 L $tonn^{-1}$	2139 L	1811 L	0
Polyethylene net	0.110 kg $bale^{-1}$	84 kg	71 kg	65 kg
Polyethylene film	1.4 kg $bale^{-1}$	1070 kg	905 kg	823 kg

The net energy values of permanent pastures, harvested grass and preserved silage were set to 0.87 FEm kg DM^{-1} (SW) and 0.85 FEm kg DM^{-1} (C, CSE). Corresponding values for Italian ryegrass pastures were 0.9 (CSE) and 1.0 (SW) FEm kg DM^{-1}.

5.4 Buildings, machinery and equipment

Only elements directly related to the farming activities were taken into account.

5.4.1 Outdoor machinery and equipment

The machinery and equipment for processes related to crop production and preservation are listed in Table 6.5.1. The Combi baler and the bale gripper were owned by three collaborating farms whereas all the other items listed belong to the studied farm alone.

Table 5.4.1 *Machinery and equipment on modelled dairy farms in central, central southeast and southwest Norway*

Machinery	'Size, working capacity'	Weight (kg)	Service time (years)
New tractor 5yr	90 kW	4500	15
Old tractor 15yr	40 kW	2500	15
Equipment			
Sprayer	600 l, 10m	200	12
Reversible plough	3-furrow, 41 cm	1400	12
Leveller (1)	3.5 m	1400	20
Tine harrow	3.7 m	1000	12
Manure tanker with splash plate spreader	6 m^3, 12 m	1000	12
Slurry mixer		200	12
Slurry vacuum pump		500	12
Disk fertilizer spreader	12 m	200	10
Seeder	3 m	200	15
Roller	3.7 m	1500	20
Mower	2.8 m	1500	12
Combi baler (2)	20 bales h^{-1}	4200	10
Bale gripper (2)		140	12
Bale lifter		160	12
Trailer	9900 kg	2300	15

(1) Central and central southeast Norway only
(2) Used by three collaborating farms

The equipment used by the contractor taking care of lime-spraying (tractor and wagon), stone removal (SW) and a polyethylene diesel tank with a pump which is regularly found on Norwegian farms, were not included in the inventory.

Grazing, both on permanent pastures and arable land, demands fences (Table 5.5.2). On the arable land the fencing was provided by conductive thread (polyethylene and steel), fencing posts (fibreglass) at every 7th meter and a connected electronic fencer supplied with energy from a battery. This included fencing around two separate paddocks and along both sides of a pathway from the barn to the paddocks. The fences around the paddocks were supposed successively moved according to a rotational grazing system. The fencing of the permanent pasture was provided by (galvanized) steel wire mesh with impregnated wooden posts at every second meter. Zink and aluminium for the galvanization process and watering device are not included. Neither is transport work related to the establishment of the fences.

Table 5.4.2. *Fencing materials included in the inventory of three Norwegian dairy farms in central (C), central southeast (CSE) and southwest (SW) Norway, and their service time.*

	Material		Amount		Service time
		C	CSE	SW	(years)
Arable land					
Fencing posts	Glass fibre	38.0 kg	37.7 kg	48.9 kg	5
Thread	polyethylene	8.4 kg	8.4 kg	10.8 kg	5
Electric Fencing power		3.0 kg	3.0 kg	3.0 kg	5
Permanent pasture					
Fencing posts	Pine	2.2 m^3	3.8 m^3	3.2 m^3	20
Impregnation materials (Tanalith)	copper carbonate ethanolamine complex	2.1 kg	3.8 kg	3.2 kg	20
	Tebuconazole	0.1 kg	0.1 kg	0.1 kg	20
	Monoethanol-amine	8.0 kg	14.0 kg	12.0 kg	20
Wire mesh	Steel	280.0 kg	492.8 kg	422.4 kg	20
Fencing posts	Glass fibre			2.6 kg	5
Thread	Polyethylene			0.6 kg	5
Electric Fencing power battery				3.0 kg	5

The amount of fencing material was related to the size of pasture areas. In SW electric fences were partly replaced by permanent stone fences which surround the agricultural land areas.

Data on active agents in the impregnated wooden fence posts were given by M. Damm, Norsk Treteknisk Institutt (pers. comm.).

5.4.2 Buildings and indoor equipment

Buildings and indoor machinery taken into account in the inventories are listed in Table 6.5.3. The barn (Appendix 1) included a feed storage room with two concrete tower-silos, which were not in use as the total amount of harvested forage was baled. We assumed that fixed interiors were included in the construction plan as well as calculated costs. In addition we included: a milking pipeline with all related equipment, a steel cooler vat, a feeding car for cutting and distribution of baled silage (TKS F2 Combi, TKS Agri), a glass-fibre concentrate silo (http://www.felleskjopet.no/landbruk/Documents/Interne/I-mek/Salgsmateriell/Produktkatalog%20Helly%20Hansen.pdf), and a wheel wagon for manual distribution of concentrates (UM-8003, UM Underhaug AS, Nærbø, Norway).

***Table 5.4.3**. Sizes, costs and service times of buildings and indoor machinery at three modelled dairy farms in central (C), central southeast (CSE) and southwest (SW) Norway.*

	Size	Building cost	Service time	Farm
Shed	200 m^2	200 000	40	All
Barn[1)]	470 m^2	3 400 000	40	C, CSE
Barn[1)]	540 m^2	4 000 000	40	SW
Milking pipeline (all inclusive)	50 m	250 000	40	C, CSE
Milking pipeline (all inclusive)	55 m	270 000	40	SW
Cooler vat	1500 L	100 000	20	All
1 feeding car	2.0 m^3	95000	10	All
1 concentrate silo	6.5 m^3	9000	10	All
1 concentrate wagon	180 l	3000	10	All

[1)] Including slurry store, fixed interiors, lights and ventilation system

Dairy cows were estimated to occupy 67 % of the total building area, heifers > 1 year 14 %, bulls > 1 year 9 % and the young stock < 1 year 10 %.

We assumed that the shed was a steel construction.

5.5 Energy consumption

5.5.1 Diesel

The calculations leading to the data presented in Table 5.5.1-5.5.3 were based on the assumption that the fields were quadratic and averages 2.0 ha. Further, the transport of machinery and equipment to the field and back, was set as 2000 m per field, i.e. 1000 m per ha of area for C and CSE. For SW the related transport was set to 3000 m per field, i.e. 1500 m per ha of area. The processes were sorted according to Figure 4.1 in established sward, standing crop, fresh forage for preservation and preserved forage at barn.

Transport work related to the establishment of the infrastructure needed for grazing was regarded to be small and not accounted for.

Mowing was conducted once (CSE, C) or twice (SW) a year for the area with a standing crop originating directly from newly established swards. The remaining area was mown two times in CSE and C, and three (timothy leys) or four (perennial ryegrass leys) times a year in SW. 1-2 ha were defined as being grazed only, without diesel expenditure.

For the transfer of data from area to the functional unit for forage, FEm, the total yield of fresh forage was related to the diesel spent for baling and related transport

The calculations leading to baled forage were based on the assumption that the baling capacity is 20 per hour and that one hour is spent per 20 bales collected and placed at the field side. Further, the loading, transport and unloading of bales from field to barn was assumed to occur at a rate of 16 bales per hour (C, CSE) and about 13 bales per hour (SW), due to eight bales per load. For the transfer of diesel consumption per bale to consumption per functional unit (FEm), litres per bale were divided by feed units per bale.

Table 5.5.1a. Details on labour and diesel consumption associated with forage production as calculated for the modelled farm in southwest Norway

Process	Workload (L h^{-1} kW^{-1})	Tractor (kW)	Diesel (L h^{-1})	Speed (km h^{-1})	Labour (h ha^{-1})	Diesel (L ha^{-1})	Area ha
Processes leading to established sward of perennial crops							
Chemical fallowing	0.12	90	10.8	8	0.39	4.2	3.9
Related transport	0.12	90	10.8	15	0.1	1.1	3.9
Ploughing	0.19	90	17.1	10	1.47	25.1	3.9
Related transport	0.12	90	10.8	15	0.1	1.1	3.9
Liming	0.19	120	22.8	12	0.23	5.2	3.9
Related transport	0.12	120	14.4	15	0.1	1.4	3.9
Stone removal	0.16	90	14.4	1.42	1.4[1]	20.2	3
Stone transport	0.16	90	14.4	15	0.14	2.0	3
Related transport	0.12	90	10.8	15	0.1	1.1	3.9
Mixing manure	0.25	90	22.5		0.85[1,2]	19.1[2]	3.9
Fertilization organic (44 m^{3}ha^{-1})	0.19	90	17.1	3.0	1.07	18.3	3.9
Related transport	0.16	90	14.4	15	1.67	24.0	3.9
Harrowing	0.19	90	17.1	8.5	0.42	7.2	3.9
Related transport	0.12	90	10.8	15	0.1	1.1	3.9
Fertilization mineral	0.12	90	10.8	10	0.15	1.6	3.9
Related transport	0.12	90	10.8	15	0.1	1.1	3.9
Sowing	0.12	40	4.8	7.5	0.55	2.6	3.9
Related transport	0.12	40	4.8	12	0.1	0.5	3.9
Rolling	0.12	40	4.8	6	0.58	2.8	3.9
Related transport	0.12	40	4.8	12	0.1	0.5	3.9
Spraying	0.12	90	10.8	8	0.39	4.2	3.9
Related transport	0.12	90	10.8	15	0.1	1.1	3.9
Processes leading to established sward of annual ryegrass							
Ploughing	0.19	90	17.1	10	1.47	25.1	2
Related transport	0.12	90	10.8	15	0.1	1.1	2
Mixing manure	0.25	90	22.5		0.85[1,2]	19.1[2]	2
Fertilization organic (44 m^{3}ha^{-1})	0.19	90	17.1	3.0	1.07	18.3	2
Related transport	0.16	90	14.4	15	1.67	24.0	2
Harrowing	0.19	90	17.1	8.5	0.42	7.2	2
Related transport	0.12	90	10.8	15	0.1	1.1	2
Fertilization mineral	0.12	90	10.8	10	0.16	1.8	2
Related transport	0.12	90	10.8	15	0.1	1.1	2
Sowing	0.12	40	4.8	7.5	0.55	2.6	2
Related transport	0.12	40	4.8	12	0.1	0.5	2
Rolling	0.12	40	4.8	6	0.58	2.8	2
Related transport	0.12	40	4.8	12	0.1	0.5	2

[1]Labour set (not calculated by 'Drift')

[2] This figure is valid only when one stirring/mixing operation (duration of 5 h) is related to application on 3.9+2=5.9 ha (perennial + annual crops).

[3]Stone removal are conducted on only 3 ha therefor it sums up to : (23.2*3/3.9 + 123.9)*3.9 = 552.8

[4] This figure is valid only when one stirring/mixing operation (duration of 5 h) is related to application on 15.6 ha.

***Table 5.5.1b**. Details on labour and diesel consumption associated with forage production as calculated for the modelled farm in southwest Norway.*

Process	Workload (L h^{-1} kW^{-1})	Tractor (kW)	Diesel (L h^{-1})	Speed (km h^{-1})	Labour (h ha^{-1})	Diesel (L ha^{-1})	Area ha
Processes leading to standing crop of ley (1-4)							
Mixing manure 1	0.25	90	22.5		0.32[1,4]	7.2[4]	15.6
Fertilization organic 1 (22 m^3ha^{-1})	0.19	90	17.1	7	0.55	9.4	15.6
Related transport	0.16	90	14.4	15	0.83	12.0	15.6
Mixing manure 2	0.25	90	22.5		0.32[1,4]	7.2[4]	15.6
Fertilization organic 2 (22 m^3ha^{-1})	0.19	90	17.1	7	0.55	9.4	15.6
Related transport	0.16	90	14.4	15	0.83	12.0	15.6
Fertilization mineral 1	0.12	90	10.8	10	0.17	1.9	15.6
Related transport	0.12	90	10.8	15	0.1	1.1	15.6
Fertilization mineral 2	0.12	90	10.8	10	0.17	1.9	15.6
Related transport	0.12	90	10.8	15	0.1	1.1	15.6
Fertilization mineral 3	0.12	90	10.8	10	0.17	1.9	15.6
Related transport	0.12	90	10.8	15	0.1	1.1	15.6
Fertilization mineral 4	0.12	90	10.8	10	0.17	1.9	5.9
Related transport	0.12	90	10.8	15	0.1	1.1	5.9
Processes leading to standing crop on newly established ley							
Fertilization mineral 1	0.12	90	10.8	10	0.15	1.6	3.9
Related transport	0.12	90	10.8	15	0.1	1.1	3.9
Processes leading to standing crop on annual ryegrass							
Fertilization mineral 1	0.12	90	10.8	10	0.16	1.8	2
Related transport	0.12	90	10.8	15	0.1	1.1	2
Fertilization mineral 2	0.12	90	10.8	10	0.16	1.8	2
Related transport	0.12	90	10.8	15	0.1	1.1	2
Fertilization mineral 3	0.12	90	10.8	10	0.16	1.8	2
Related transport	0.12	90	10.8	15	0.1	1.1	2
Processes leading to standing crop on permanent pasture							
Fertilization mineral 1	0.12	90	10.8	10	0.16	1.8	3
Related transport	0.12	90	10.8	15	0.1	1.1	3
Fertilization mineral 2	0.12	90	10.8	10	0.16	1.8	3
Related transport	0.12	90	10.8	15	0.1	1.1	3
Fertilization mineral 3	0.12	90	10.8	10	0.16	1.8	3
Related transport	0.12	90	10.8	15	0.1	1.1	3
Fertilization mineral 4	0.12	90	10.8	10	0.16	1.8	3
Related transport	0.12	90	10.8	15	0.1	1.1	3
Harrowing	0.19	90	17.1	8.5	0.42	7.2	1
Related transport	0.12	90	10.8	15	0.1	1.1	1
Re-seeding	0.12	40	4.8	7.5	0.55	2.6	1
Related transport	0.12	40	4.8	12	0.1	0.5	1
Spraying	0.12	90	10.8	8	0.39	4.2	0.6
Related transport	0.12	90	10.8	12	0.1	0.5	0.6
Distribution of lime	0.19	120	22.8	10	0.21	4.8	0.5
Related transport	0.12	120	14.4	15	0.1	1.4	0.5
Processes leading to fresh forage for preservation							
Mowing	0.19	90	17.1	10	0,60	10.3	58
Related transport	0.12	90	10.8	15	0.1	1.1	58

Footnotes: see Table 5.5.1a

***Table 5.5.1c**. Details on labour and diesel consumption associated with forage production as calculated for the modelled farm in southwest Norway.*

Process	Workload ($L\ h^{-1}\ kW^{-1}$)	Tractor (kW)	Diesel ($L\ h^{-1}$)	Speed ($km\ h^{-1}$)	Labour ($h\ bale^{-1}$)	Diesel ($L\ bale^{-1}$)
Processes leading to preserved forage at barn						
Baling	0.22	90	19.8		0.05[1]	1
Related transport, field	0.12	90	10.8		0.05[1]	0.54
Related transport, barn	0.16	90	14.4		0.078	1.125

Footnotes: see Table 5.5.1a

Table 5.5.2. *Details on labour and diesel consumption associated with forage production as calculated for the modelled farm in central Norway.*

Process	Workload ($L\ h^{-1}\ kW^{-1}$)	Tractor (kW)	Diesel ($L\ h^{-1}$)	Speed ($km\ h^{-1}$)	Labour ($h\ ha^{-1}$)	Diesel ($L\ ha^{-1}$)	Area (ha)
Processes leading to established sward							
Chemical fallowing	0.12	90	10.8	8	0.39	4.2	4.5
Related transport	0.12	90	10.8	15	0.07	0.8	4.5
Ploughing	0.19	90	17.1	7.5	1.73	29.6	4.5
Related transport	0.12	90	10.8	15	0.07	0.8	4.5
Liming	0.19	120	22.8	12	0.26	5.9	4.5
Related transport	0.12	120	14.4	15	0.07	1.0	4.5
Levelling	0.19	90	17.1	8.5	0.42	7.2	4.5
Related transport	0.12	90	10.8	15	0.07	0.8	4.5
Stone removal	0.12	90	10.8		0.20[1]	2.3	4.5
Related transport	0.12	90	10.8	15	0.07	0.8	4.5
Mixing manure	0.25	90	22.5		1.11[1,2]	25.0[2]	4.5
Fertilization organic (36 m^3)	0.19	90	17.1	3.8	0.88	15.5	4.5
Related transport	0.16	90	14.4	15	0.89	12.8	4.5
Harrowing	0.19	90	17.1	8.5	0.42	7.2	4.5
Related transport	0.12	90	10.8	15	0.07	0.8	4.5
Fertilization mineral	0.12	90	10.8	10	0.17	1.8	4.5
Related transport	0.12	90	10.8	15	0.07	0.8	4.5
Sowing	0.12	40	4.8	7.5	0.55	2.6	4.5
Related transport	0.12	40	4.8	12	0.08	0.4	4.5
Rolling	0.12	40	4.8	6	0.58	2.8	4.5
Related transport	0.12	40	4.8	12	0.08	0.4	4.5
Spraying	0.12	90	10.8	8	0.39	4.2	4.5
Related transport	0.12	90	10.8	15	0.07	0.8	4.5
Processes leading to standing crop in years of ley (1-4)							
Fertilization mineral 1	0.12	90	10.8	10	0.26	2.8	18
Related transport	0.12	90	10.8	15	0.07	0.8	18
Fertilization mineral 2	0.12	90	10.8	10	0.19	2.1	18
Related transport	0.12	90	10.8	15	0.07	0.8	18
Mixing manure 1	0.25	90	22.5		0.28[1,3]	6.3	18
Fertilization organic 1	0.19	90	17.1	7	0.48	8.3	18
Related transport	0.16	90	14.4	15	0.44	6.3	18
Mixing manure 2	0.25	90	22.5		0.28[1,3]	6.3[3]	18
Fertilization organic 2	0.19	90	17.1	7	0.48	8.3	18
Related transport	0.16	90	14.4	15	0.44	6.3	18
Processes leading to fresh forage for preservation							
Mowing	0.19	90	17.1	10	0.6	10.3	40.5
Related transport	0.12	90	10.8	15	0.07	0.8	40.5
Processes leading to preserved forage at barn							
					($h\ bale^{-1}$)	($L\ bale^{-1}$)	
Baling	0.22	90	19.8		0.05[1]	1	
Related transport, field	0.12	90	10.8		0.05[1]	0.54	
Related transport, barn	0.16	90	14.4		0.06[1]	0.86	

[1] Labour set (not calculated by 'Drift')

[2] This figure is valid only when one stirring/mixing operation (duration of 5 h) is related to application on 4.5 ha.

[3] This figure is valid only when one stirring/mixing operation (duration of 5 h) is related to application on 18 ha.

Table 5.5.3a. *Details on labour and diesel consumption associated with forage production as calculated for the modelled farm in central southeast Norway.*

Process	Workload ($L\ h^{-1}\ kW^{-1}$)	Tractor (kW)	Diesel ($L\ h^{-1}$)	Speed ($km\ h^{-1}$)	Labour ($h\ ha^{-1}$)	Diesel ($L\ ha^{-1}$)	Area (ha)
Processes leading to established sward of perennial crops							
Chemical fallowing	0.12	90	10.8	8	0.39	4.2	3.9
Related transport	0.12	90	10.8	15	0.07	0.8	3.9
Ploughing	0.19	90	17.1	10	1.47	25.1	3.9
Related transport	0.12	90	10.8	15	0.07	0.8	3.9
Liming	0.19	120	22.8	12	0.26	5.9	3.9
Related transport	0.12	120	14.4	15	0.07	1.0	3.9
Levelling	0.19	90	17.1	8.5	0.43	7.4	3.9
Related transport	0.12	90	10.8	15	0.07	0.8	3.9
Stone removal	0.12	90	10.8		0.20[1]	2.3	3.9
Related transport	0.12	90	10.8	15	0.07	0.8	3.9
Mixing manure	0.25	90	22.5		0.85[1,2]	19.1	3.9
Fertilization organic (55 m^3)	0.19	90	17,1	2.7	1.32	22.6	3.9
Related transport	0.16	90	14.4	15	1.11	16.0	3.9
Harrowing	0.19	90	17.1	8.5	0.42	7.2	3.9
Related transport	0.12	90	10.8	15	0.07	0.8	3.9
Fertilization mineral	0.12	90	10.8	10	0.17	1.8	3.9
Related transport	0.12	90	10.8	15	0.07	0.8	3.9
Sowing	0.12	40	4.8	7.5	0.55	2.6	3.9
Related transport	0.12	40	4.8	12	0.07	0.3	3.9
Rolling	0.12	40	4.8	6	0.58	2.8	3.9
Related transport	0.12	40	4.8	12	0.07	0.3	3.9
Spraying	0.12	90	10.8	8	0.39	4.2	3.9
Related transport	0.12	90	10.8	15	0.07	0.8	3.9
Processes leading to established sward of annual ryegrass							
Ploughing	0.19	90	17.1	10	1.47	25.1	2
Related transport	0.12	90	10.8	15	0.07	0.8	2
Levelling	0.19	90	17.1	8.5	0.43	7.4	2
Related transport	0.12	90	10.8	15	0.07	0.8	2
Stone removal	0.12	90	10.8		0.20[1]	2.3	2
Related transport	0.12	90	10.8	15	0.07	0.8	2
Mixing manure	0.25	90	22.5		0.85[1,2]	19.1[2]	2
Fertilization organic (55 m^3)	0.19	90	17.1	1.9	0.78	13.3	2
Related transport	0.16	90	14.4	15	1.78	25.6	2
Harrowing	0.19	90	17.1	8.5	0.42	7.2	2
Related transport	0.12	90	10.8	15	0.07	0.8	2
Sowing	0.12	40	4.8	7.5	0.55	2.6	2
Related transport	0.12	40	4.8	12	0.07	0.8	2
Rolling	0.12	40	4.8	6	0.58	2.8	2
Related transport	0.12	40	4.8	12	0.07	0.8	2
Processes leading to standing crop in years of ley (1-4)							
Fertilization mineral 1	0.12	90	10.8	10	0.23	2.5	15.6
Related transport	0.12	90	10.8	15	0.07	0.8	15.6
Fertilization mineral 2	0.12	90	10.8	10	0.19	2.1	15.6
Related transport	0.12	90	10.8	15	0.07	0.8	15.6
Mixing manure 1	0.25	90	22.5		0.43[1,3]	9.6[3]	11.7
Fertilization organic 1 (20 m^3)	0.19	90	17.1	7	0.66	11.3	11.7
Related transport	0.16	90	14.4	15	0.56	8.0	11.7
Mixing manure 2	0.25	90	22.5		0.43[1,3]	9.6[3]	11.7
Fertilization organic 2 (20 m^3)	0.19	90	17.1	7	0.66	11.3	11.7
Related transport	0.16	90	14.4	15	0.56	8.0	11.7

Footnotes: see Table 5.5.2

***Table 5.5.3b**. Details on labour and diesel consumption associated with forage production as calculated for the modelled farm in central southeast Norway*

Process	Workload ($L\ h^{-1}\ kW^{-1}$)	Tractor (kW)	Diesel ($L\ h^{-1}$)	Speed ($km\ h^{-1}$)	Labour ($h\ ha^{-1}$)	Diesel ($L\ ha^{-1}$)	Area (ha)
Processes leading to standing crop on annual ryegrass							
Fertilization mineral	0.12	90	10.8	10	0.18	1.9	2
Related transport	0.12	90	10.8	15	0.07	0.8	2
Processes leading to standing crop on permanent pasture							
Fertilization mineral	0.12	90	10.8	**10**	0.17	1.8	3.5
Related transport	0.12	90	10.8	15	0.07	0.8	3.5
Processes leading to fresh forage for preservation							
Mowing	0.19	90	17.1	10	**0.60**	10.3	37
Related transport	0.12	90	10.8	15	0.07	0.8	37
Processes leading to preserved forage at barn							
					($h\ bale^{-1}$)	($L\ bale^{-1}$)	
Baling	0.22	90	19.8		0.05[1]	1	
Related transport, field	0.12	90	10.8		0.05[1]	0.54	
Related transport, barn	0.16	90	14.4		0.0625[1]	0.86	

Footnotes: See Table 5.5.2

The total diesel consumption was estimated to be about 3900(C), 3400 (CSE) and 4800 (SW), L year^{-1}. Ploughing, mixing, transport and spreading of manure and preservation/baling were the most time-and energy-consuming processes.

5.5.2 *Electricity*

The annual consumption of electricity related to farming activities were set to 26000 kWh at all three modelled farms.

5.6 Pre-farm transport

The management of the farm requires several inputs from the outer boundary which in turn requires transport to the farm-gate. Transport of input elements of major importance and/or volume (lime, mineral fertilizer, concentrate mixtures, sawdust, matrasses, veterinary service) were included in the inventory whereas transport of small articles of consumption (by example: plastic film, net and additives for silage making, as well as mineral supplements) are not considered.

The figures in Table 5.6.1 represent one way distances. We assumed that mixed concentrates and mineral supplements were delivered by the local plants, i.e. Felleskjøpet Rogaland-Agder (SW), Felleskjøpet Agri Steinkjer (C), and Felleskjøpet Stange (CSE) in batches à 5-6 tons from a lorry loaded with approximately 30 tons for a delivery to 5-6 farmers on the same route (pers. com., Felleskjøpet Agri).

Table 5.6.1 *Transport methods and transport distances from the outer boundary to farm gate for mineral fertilizers, lime, sawdust, purchased feeds, cow mattresses and veterinary services included in the inventory of three modelled dairy farms in central, central southeast and southwest Norway.*

Product	Transport method	SW (km)	C (km)	CSE (km)
OPTI-NS	Ship	800	800	800
OPTI-NS	Lorry	580	580	185
OPTI-NS	Lorry	4		
OPTI-NS	Tractor		20	7
NPK- fertilizer (25-2-6)	Lorry			310
NPK- fertilizer (25-2-6)	Tractor			7
Lime	Ship	1500		
Lime	Lorry	25		
Lime	Tractor		30	15
Sawdust	Lorry	4	15	10
Sawdust	Lorry	850		
Purchased feeds	Lorry	25	30	95
Veterinary	Passenger car	125	250	250
Matress	Ship	12000	12000	12000
Matress	Lorry	580	580	185

We assumed that a tractor with the trailer was to collect the fertilizer and seeds from the local warehouse (once a year) and sawdust from a local sawmill or warehouse (seven times a year). The lime was either collected from a local quarry once a year by the farmer using his own tractor (C) or transported by lorry to the farm (CSE, SW). The number of visits by the vet per farm (C and CSE: 25, SW: 31) were roughly estimated based on informal interviews of a few local vets in the municipalities of Verdal, Levanger and Inderøy (Håvard Okkenhaug et al., pers.comm.). The driving distances by the vet per visit were also roughly estimated.

6. Emissions

The construction of indicators for *impact* of milk and meat production on greenhouse effect, eutrophication and acidification (Table 6.1.1) is addressed in this chapter.

Table 6.1.1. *Components used for developing indicators of impact on the greenhouse effect, eutrophication and acidification*

Indicator	Factors/compounds considered
Greenhouse gas emissions	CO_2, N_2O, CH_4
Erosion and eutrophication	Soil loss, NO_3, P
Acidification	NH_3, NOX, SO_2

For details on farming processes, diesel consumption and used chemicals with toxic effects, see chapter 6.

6.1 Greenhouse gas emissions

Global Warming Potential (GWP) is an estimate of global warming contribution (Earth's radiative forcing) of a given greenhouse gas. GWP compares different gases in a relative scale to the same mass of CO_2 (GWP for CO_2 equals 1). In this inventory the GWP calculations were related to an emission response over a time interval of 100 years. Relevant for the dairy farm case is the methane (CH_4) 100 year GWP of 25 and the nitrous oxide (N_2O) 100 year GWP of 298 (IPCC, 2007).

The greenhouse gas emissions were calculated in line with the Norwegian Emission Inventory 2010 (SSB, 2010) and modified according to changes found in the latest IPCC standards (IPCC, 2006), as outlined below.

6.1.1 CO_2 emissions

Direct CO_2 emissions caused by liming and diesel combustion were addressed and attributed to farm management processes.
Soil organic C changes were assumed negligible both for the permanent pastures and in total over the years between renovations of leys. Cultivated area has been managed for decades as leys/pastures, and soil organic matter was therefore assumed to be close to an equilibrium state. For the same reason, grazing of outlying fields was also assumed to have negligible effect on net soil C storage.

Liming

For details on liming practices, see chapter 6.3.

Although it was assumed that liming was performed after breaking of leys, the average annual CO_2 emissions were calculated in accordance with IPCC (2006) as if the leys were limed annually with an accordingly adjusted lime requirement, in accordance with IPCC (IPCC, 2006; Equation 11.12). Emission factors used were 0.12 and 0.13 kg of C per kg of limestone and dolomite, respectively.

Diesel consumption

For details on farming processes and diesel consumption, see chapter 6.7.
For diesel combustion, an emission factor of 2.6391 kg CO_2 per liter was adopted (National Energy Foundation, 2010).

6.1.2 CH_4 emissions

The CH_4 emissions considered are those resulting from enteric fermentation in domestic livestock and the direct emissions occurring from manure.

Enteric fermentation

Methane is an important end product from the ruminal fermentation. A Tier 3 methodology was used (Volden & Nes, 2006), where CH_4 emissions from dairy cattle was estimated from calculations of gross energy intake and a methane conversion rate, both parameters depending on lactation yield and the concentrate proportion in the diet. CH_4 emission estimates for the replacement heifers and slaughter bulls were dependent on the age of calving and slaughtering, respectively, and the carcass weights.

For main characteristics of herds and feeding, see chapter 5.2.

Calculated enteric CH_4 emissions for dairy cows according to the Norwegian Tier 3 method are about 10 % higher than estimates according to IPCC Tier 1 or Tier 2 estimates (IPCC 2006), mostly due to differences in the calculation methods.

Manure

Some organic material in manure is transformed to CH_4 in anaerobic environments. The CH_4 emissions were estimated in accordance with the Norwegian default IPCC Tier 2 method (SSB 2010; IPCC 2006). The default standards were based on rather old data and related to low milk yields (about 5000-5500 kg ECM per cow yr^{-1}) compared to the 7100-7300 kg ECM in our case. Therefore, the daily manure production for dairy cattle was increased from 45 to 56 kg fresh manure $head^{-1}$. Most likely, the increased estimate of manure produce is still too low (Karlengen *et al.*, 2012). The estimate of CH_4 emission from manure accounts for gross energy intake and feed digestibility, animal production of manure, and the manure handling practices and storage conditions.

6.1.3 N_2O emissions

Estimates of N_2O emissions basically follow the methods described in The Norwegian Emission Inventory (SSB, 2010). Modifications in line with the latest IPCC standards (IPCC 2006) are described.

It was distinguished between direct and indirect N_2O emissions. The direct N_2O emission sources were N in manure, N applied in fertilizer, and N in plant residues left after crop harvest. The indirect N_2O emission originated from the re-deposition of N lost by volatilization and the N lost through leaching and runoff.

Direct N_2O emissions

It was assumed that an increase in available N enhances the production of N_2O through processes of nitrification and denitrification. Nitrogen sources included in the direct N_2O emission estimates used in this study were mineral N applied as fertilizer, manure N in the storage period, applied organic manure N to cultivated area, and N in above-ground and below-ground crop residues. The organic matter in soil was assumed in a steady state, which is reflecting no crucial change in management over the latest decades. Therefore, no N_2O emission was calculated as an effect of changes in soil humus N.

For the N applied as mineral fertilizer or as animal manure, the default N_2O emission factor value was changed from 0.0125 (SSB, 2010) to 0.01 kg N_2O-N kg^{-1} N in accordance to the latest IPCC standard (IPCC, 2006). The IPCC standard makes use of the amount of N applied (before volatilization, leaching and runoff losses) as the source for direct N_2O

emissions, also implemented in these calculations. Finally, N_2O emission from biological N fixation was assumed negligible (IPCC, 2006).

The yearly production of N in manure for dairy cattle was increased from the default value of 82 (SSB, 2010) to 102 kg N head^{-1} yr^{-1}. This is more in line with the calculation method in NorFor-Plan (Hoen *et al.*, 2007) and the milk yield per cow in the present cases. Still, it is lower than estimates of N produce in manure according to Swedish standards (Albertson, 2009) (about 108 kg N head^{-1} yr^{-1} for an average milk produce of 7100 kg ECM cow^{-1}) and also lower than estimates according to Karlengen *et al.* (2012).

Emission from stored manure N was estimated using the default emission factor of 0.001 kg N_2O-N per kg manure N. Direct N_2O emission after spreading of manure is according to default settings 10 times higher than the loss from manure in the storage cellar. For droppings the N_2O emission factor of 0.02 kg N_2O-N kg^{-1} N was applied.

Estimate of crop N residues follows IPCC standards (IPCC 2006; table 11.2). However, in the grass systems these emissions are not easy predictable. The breaking of leys leads to N mineralization and N_2O pulses from the organic matter build up over years with perennial grass/clover.

Indirect N_2O emissions

Losses of N from agricultural areas ending up in surrounding environments will be potential sources for indirect emissions of N_2O. One pathway is the volatilization of NH_3 and oxides (NO_x), and the deposition of these gases and their products (NH_4^+ and NO_3^-) onto surrounding soils and water surfaces. Another pathway is through the leaching and runoff of N.

Indirect N_2O emissions following N volatilization

N volatilization from mineral N fertilizer was set in accordance to IPCC standards (IPCC 2006) as 0.10 kg (NH_3 + NO_x)-N per kg N applied, which is 10-fold higher than the default figure for the Yara Opti NS^{TM} (27-0-0) fertilizer given in the Norwegian emission inventory (SSB 2010).

The Statistics Norway's NH_3 model was used to calculate the NH_3 volatilized from manure (SSB 2010). A total of 7 % of total N in manure was assumed lost as NH_3 in the animal room and the storage cellar together. From grazing animals a NH_3-N loss of 7.5 % of N in the droppings was applied. A 35 % loss of N from manure spread on cultivated area was entered into the calculations.

The annual indirect N_2O emission from atmospheric deposition of N to soils and water surfaces was then calculated in accordance to IPCC standards after multiplication of the N volatilized (from fertilizer and manure) and the default N_2O emission factor of 0.01 kg N_2O-N per kg N volatilized (IPCC, 2006; Equation 11.9).

Indirect N_2O emissions following N loss through leaching and runoff

N loss through leaching and runoff was estimated as 18 % of N applied to soil (SSB, 2010) in fertilizer and manure corrected for the volatilized N loss. These waterway N losses will highly depend on soil and meteorological conditions.

The annual indirect N_2O emission through the water pathway was then calculated in accordance to IPCC standards using the default N_2O emission factor of 0.0075 kg N_2O-N per kg N lost (IPCC, 2006; Equation 11.9). This latest IPCC emission factor value is only one third of the default Norwegian value (SSB, 2010).

6.2 Erosion and eutrophication

The risk for P loss and erosion in the year of plowing and re-seeding is high compared to the years with ley. P losses also occur through drainage and surface water runoff, the time periods after fertilizer and manure applications are the most critical. P loss after thawing/freezing of plant materials is well known through off seasons for plant growth.

As a result of yearly applied manure for decades the P status in soil was assumed to be medium to high (P-AL 8-12) in C and CSE and high (P-AL 16-20) in SW. The erosion risks were regarded as medium, medium-high and low, in, C, CSE and SW respectively, according to official classifications (The Norwegian Forest and Landscape Institute, 2011).

Total phosphorus (P) loss from the farm of 1.5 kg P ha^{-1} yr^{-1} in C and CSE and 2 kg P ha^{-1} yr^{-1} in SW were set with support from results from several field experiments and monitoring series.

Table 6.2.1. Annual monitored/estimated losses of soil and P (kg ha^{-1}) from some relevant agricultural areas at different locations

Locations	**Soil loss kg ha^{-1} yr^{-1}**	**P loss kg ha^{-1} yr^{-1}**
Kvithamar (arable land) [1)]	329-1080	1-2.4
Hotran (JOVA – annual mean) [2)]	2820	4.0
Naurstad (JOVA – annual mean) [2)]	840	3.8
Volbu (JOVA – annual mean) [2)]	110	0.4
Time (JOVA – annual mean) [2)]	110	1.4
Västre Götaland [3)]	-	0.5

[1)]Cereals monitored (field lysimeter in Nord-Trøndelag) in the period 1991-1994 (Oskarsen *et.al.*, 1996)

[2)]Watershed monitoring program (JOVA) in the period 1992-2011 (Hauken *et.al.*, 2012)

[3)]Strid & Flysjø, 2007

6.3 Acidification

Acidification Potential (AP) was based on the contributions to acid deposition in the form of H^+ (protons), normally given in SO_2 equivalents. Contribution factors to the AP for essential substances are given in Table 7.3.1

Table 6.3.1. Acidification potentials

Substance	**Acidification potential[1)] (AP in kg SO_2-equiv./kg)**
SO_2	1.00
NO_x	0.70
NH_3[)]	1.88

[1)]Heijungs et al. 1992

The acidifying compounds included (on farm) in this work were NO_x from diesel consumption, volatilized NH_3 from manure, and NH_3 and NO_x from fertilizer. Emissions of NO_x from diesel consumption were estimated on the basis of Li *et al.* (2006). SO_2 emissions from diesel were assumed to be negligible. The sum of volatilized NH_3-N and NO_x-N from fertilizer applied was calculated as described above (chapter 7.1.3). Volatilized NH_3-N of applied N in fertilizer was set to 2 % (Bouwman, 1997), and the remaining 8 % of emitted fertilizer N was assumed to be NO_x-N.

6.4 Toxicity

Active agents and preparations used in medications (Table 5.2.5), cleaning and cooling (Table 5.2.6), crop production (Table 6.3.1) and fencing (Table 5.2.7) are listed earlier.

7. References

Albertson, B. 2009. Riktlinjer för gödsling och kalkning 2010. Jordbruksverket. Jordbruksinformation 13. (*in Swedish*).

Bakken, A., Lunnan, T., Høglind, M., Harbo, O., Langerud, A., Rogne, T. & Ekker, A. 2009. Mer og bedre grovfôr som basis for norsk kjøtt- og mjølkeproduksjon. Resultater fra flerårige høstetidsforsøk I blandingseng med timotei, engsvingel og rødkløver. Bioforsk Rapport 38 (4) 95 pp. (*In Norwegian*).

Berg, K. 1997. Rundballer og pressaft, Heje 1997. Handbok for jordbruket, s. 205 (*in Norwegian*).

Bioforsk. 2010. Gjødslingshåndbok, http://www.bioforsk.no/ikbViewer/page/prosjekt/tema?p_dimension_id=19190&p_menu_id=19211&p_sub_id=19191&p_dim2=19603). Accessed 04.08.10.

Bouwman, A., Lee, D., Asman, W., van der Hoek, F. & Olivier, J. 1997. A global high resolution emissions inventory for ammonia. Glo.Biogeochem. Cycl. 11(4): 561-587.

Dalgaard, T., Halberg, T. & Porter, J.R. 2001. A model for fossile energy use in Danish agriculture used to compare organic and conventional farming. Agriculture, Ecosystems and Envirionment 87: 51-65.

Davidson, B.R., Martin, B.R. & Mauldon, R.G. 1967. The application of experimental research to farm production. Journal of Farming Economy, 49: 900–907.

Degerdal, H., Tande, O. & Østby, M. 2011. Tung ball har sin pris. Bedre Gardsdrift 31 (6): 36-46.

Felleskjøpet, 2010a. Optimal produksjon av storfekjøtt. Leaflet, 19 pp. (*in Norwegian*).

Felleskjøpet, 2010b . En lommeguide til sunne og lønnsomme dyr. Pluss, 36 pp. www.felleskjopet.no. Accessed 20.11.10. (*in Norwegian*).

Flaten, O., Asheim, L.J., Dønnem, I. & Lunnan, T. 2012. The profitability of early grass silage harvesting on dairy goat farms in mountainous areas of Norway. Small Ruminant Research, 103(2): 133-142.

Flysjö, A., Cederberg, C. & Strid, I. 2008. LCA-databas för konventionella fodermedel – miljöpåverkan I samband med production. Report 772. SIK- The Swedish Institute for Food and Biotechnology, Gøteborg (*In Swedish*).

Gjerde, I. 1990. Økonomisk analyse av storfefjøs. Foredrag ved informasjonsmøte I landbruksteknikk 18. og 19. april 1990. Aktuelt frå Statens fagtjeneste for landbruket nr 7/1990.

Hauken M, Bechmann M, Stenrød M, Eggestad H-O & Deelstra, J., 2012. Erosjon og tap av næringsstoffer og plantevernmidler fra jordbruksdominerte nedbørfelt. Sammendragsrapport for overvåkingsperioden 1992-2011 fra Program for jord- og vannovervåking i landbruket (JOVA). Bioforsk Rapport 7 (78), 73 pp. (*In Norwegian*).

Heijungs, R., Guinée, J.B., Huppes, G., Lankreijer, R.M., Udo de Haes, H.A., Wegner Slesswijk, A., Ansersn, A.M.M., Eggels, P.G., van Duin, R.& de Goede, H.P. 1992. Environmental Life Cycle Assessment of production. Guide and Backgrounds. Centre of Environmental Science (CML), Leiden University, Leiden.

Hoen, H.F., Trømborg, E. & Nielsen, A. 2007. Klimagasser og bioenergi fra landbruket – kunnskapsstatus og forskningsbehov. Rapport utarbeidet på oppdrag fra: Styret for forskningsmidler over jordbruksavtalen, Fondet for forskningsavgift på landbruksprodukter og Norges forskningsråd. UMB-Rapport 2007.

IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories. Vol 4. www.ipcc.ch.

IPCC, 2007. Climate change 2007. 4th Assessment Report (AR4). 2. Changes in atmospheric constituents and in radiative forcing. Table 2.14; p. 2012.

Johansen, A. & Lunnan,T . 2005. Italiensk raigras som kvalitetsfôr til storfe og sau. Sluttrapport til Norsk Kjøttsamvirke. Rapport Planteforsk 31.03.2005, 23 pp. (*in Norwegian*).

Karlengen, I.J., Svihus, B., Kjos, N.P. & Harstad, O.M. 2012. Husdyrgjødsel: Oppdatering av mengder gjødsel og utskillelse av nitrogen, fosfor og kalium. Sluttrapport. Institutt for husdyr- og akvakulturvitenskap, Universitetet for miljø- og biovitenskap, Ås, 106 p. (*In Norwegian*).

Li, Y. & McLaughlin, N. 2006. Fuel Efficiency and Exhaust Emissions for Biodiesel Blends in an Agricultural Tractor. CSAE 05-067.

Nemecek, T., Heil, A., Huguenin, O., Meier, S., Erzinger, S., Blaser, S., Dux, D.& Zimmermann, A. 2004. Life Cycle Inventories of Agricultural Production Systems. FAL Reckenholz, FAT Taenikon, Swiss Centre for Life Cycle Inventories, Dübendorf.

Nielsen, V.& Sørensen, C.G. 2010. «DRIFT» et program for beregning af arbejdkapacitet-arbejdsbudget-arbejdsprofil. Grønne marker: Driftstekniske analyser og modelsimuleringer. http://www.landbrugsinfo.dk/Itvaerktoejer/Maskiner-og-arbejde/Sider/Beregn_arbejdsbehovet_ved_markarbejde_me.aspx. (in Danish), Accessed 20.11.10.

Norwegian Agricultural Authority, 2010. https://www.slf.dep.no. Accessed 04.08.10.

Oskarsen, H. Haraldsen, T.K., Aastveit, H.A. & Myhr, K. 1996. The Kvitahamar field lysimeter II. Pipe drainage, surface runoff and nutrient leaching. Norwegian Journal of Agricultural Science 10: 211-228

SSB 2010. Statistics Norway, (Statistisk sentralbyrå). www.ssb.no. Accessed 20. 11. 2010.

Strid, I.& Flysjø, A. 2007. Livscykelanalys (LCA) av ensilage – jämförelse av tornsilo, plansilo och rundbal. Biometri och Technik. SLU – Sveriges Lantbruksuniversitet. Uppsala.

Sundstøl, F.& Ekern, A. 1992. Det nye energivurderingssystemet for drøvtyggere (FEm-systemet) og nye energinormer. In: Husdyrforsøksmøtet, Norges Landbrukshøgskole 24.-26.mars1992., Faginfo nr 13/1992, Statens fagtjeneste for landbruket, 545-552. (*in Norwegian*).

The Norwegian Forest and Landscape Institute, 2011. http://kilden.skogoglandskap.no/map/kilden/index.jsp.

TINE Rådgiving 2008abc. Faglig rapport Ku. a)Tine Midt-Norge, b) TINE Sør, c) TINE Øst.

TINE Rådgiving 2009abc. Faglig rapport Ku, a)Tine Midt-Norge, b) TINE Sør, c) TINE Øst

TINE Rådgiving 2010 abc, Faglig rapport Ku, a)Tine Midt-Norge, b) TINE Sør, c) TINE Øst

TINE, 2010a. Godt Kvigeoppdrett. TINE Rådgiving, Leaflet, 7 pp, (*in Norwegian*).

TINE 2010b. Fôrplan for intensivt og moderat oppdrett. https://medlem.tine.no/trm/tp/1394.cms?mode=print. Accessed 30.08.2010. (*in Norwegian*).

Volden, H. & Nes, S.K. 2006. Methane emissions from enteric fermentation in Norway's cattle and sheep population. Method description. In T. Sandmo (ed.) 2010. The Norwegian Emission Inventory 2010. Documentation of methodologies for estimating emissions of greenhouse gases and long-range transboundary air pollutants. Statistics Norway, 220-229 Department of Animal and Aquacultural Sciences, Norwegian University of Life Sciences.

Yara, 2011. http:/yara.no. (accessed 22.02.11).

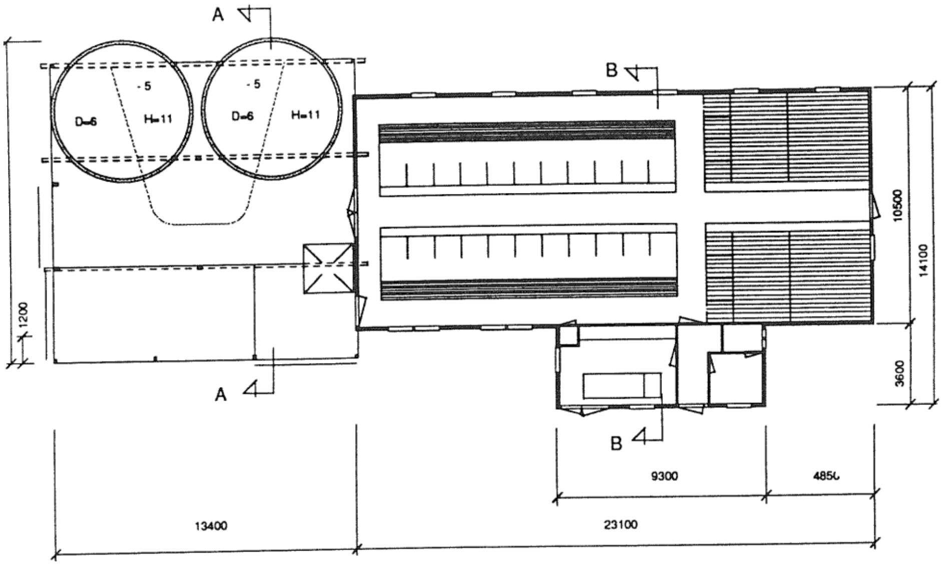
Walland, F. & Hansen, B.G. 2003. The Norwegian efficiency control. EFITA 2003 Conference, 5-9 July 2003, Hungary, 431-438.

8. Appendix

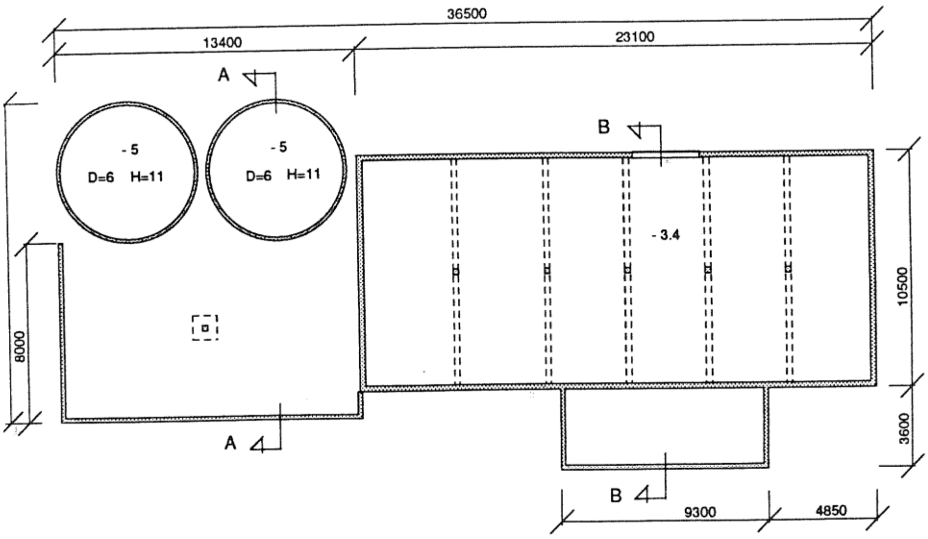
Construction plan of the barn (Gjerde 1990).

Plan nr. B 22.

Båsfjøs med kjeller, 22 båser.

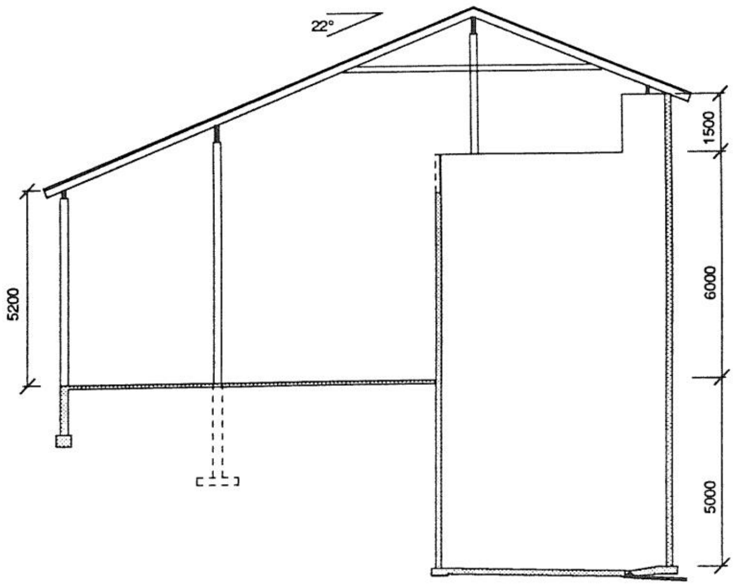


Plan 1. etasje.

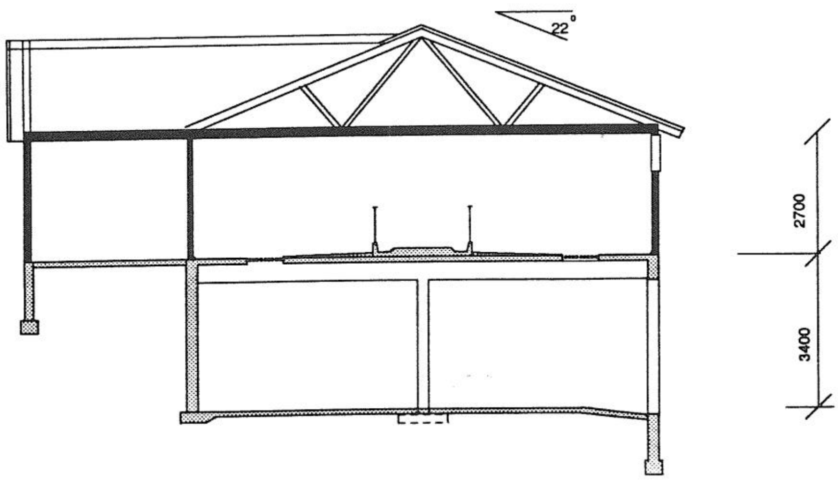


Kjellerplan.

Båsfjøs med kjeller, 22 båser forts.



Snitt A - A



Snitt B - B